TRANSACTIONS

OF THE

ROYAL IRISH ACADEMY.

I.—*On Galvanometric Deflections producible by Attrition and Contact of Metals under certain circumstances.* By Michael Donovan, Esq., *M. R. I. A.*

Read January 8, 22, and February 12, 1849.

It is known that under certain circumstances of temperature some metals when connected with a galvanometer, and brought into contact with each other, produce a deflection of the magnetic needle, which will appear to be reversed when, instead of contact, attrition is employed.

Such facts have given rise to much difference of opinion, and, as I conceive, to much misapprehension both of the phenomena and their cause. Professor Erman of Berlin, who had devoted his attention to the subject, thus sums up the opinions current upon it:—" Some observers, who appeal to the authority of Mr. Emmet, express what they consider to be the law of this action, by saying that thermo-electricity of contact is changed invariably into the opposite state by the friction of the metallic factors. Others, on the contrary, deny *in toto* the influence of friction on thermo-electric phenomena. Thus it was recently adverted to in a scientific journal as a highly paradoxical fact that, in a given case, the friction had caused a change of sign in the thermo-electric declination produced by the contact of two heterogeneous metals, but, at the same time, this 'unheard-of' fact, as it was called, was explained by supposing, gratuitously, that the friction had been effected whilst keeping the metal to be

rubbed in the naked hand, and in thus producing an accidental change of temperature. This explanation was offered on the assumption that friction in itself is not capable of producing any effect. Between the two extremes of tribo-thermo-electric omnipotence and nullity, I have tried to discover the middle course of truth."

Professor ERMAN then delivers his own opinion, and the facts from which he has deduced it:—" A bar of bismuth was joined to that branch of the rheophore of this instrument (the galvanometer) where the silver of a voltaic element (silver and zinc) produces an eastern deviation; and a bar of antimony to the other branch of the rheophore. Both of these bars were provided with handles, so that they could be employed without undergoing any change of temperature in the manipulation. When, through these being stationed in the same room, the two bars had previously arrived at the temperature of the surrounding space, no deviation whatsoever was produced by their contact, but the slightest friction of either of them against the other gave immediately an eastern deviation. This latter extended even to an entire revolution of the needle in the same direction, if the friction proceeded rather more rapidly. By gently raising the temperature of the two bars to 30° or 35° of Reaum., scale (100° or 111° Fahr.), their contact in a state of repose always produced a stationary eastern deviation of about 30°, which by rubbing was further increased to 60°, and there likewise remained invariable as long as friction continued. At length, when I cooled the bars below the temperature of the room, by the evaporation of naphtha vitrioli (sulphuric ether), their contact continually produced a western deviation, which by rubbing was instantaneously changed into a contrary or eastern one of apparently the same amount as before, and this likewise remained stationary as long as the friction continued; but, by the interruption of it the western deviation was immediately restored. This simple sketch of the phenomena of changes of intensity or even of sign, which friction, at the point of contact, gives to the deviation of a multiplicator's needle, will already suffice to exhibit it as a mere consequence of the heat produced by the action of rubbing."*

Professor ERMAN, in alluding to the difficulty of investigations of this kind, and, as he expresses it, "the arduous nature of the observations required,"

* Report of Fifteenth Meeting of British Association, June, 1845, p. 103.

informs us of the many errors into which he was led by the action of the rheophores, with which the communication between the metals experimented on and the galvanometer coil was established, heterogeneous as these metals and the wires must often be. He had hoped that the specific action of the rheophores "on the thermo-electric elements could be neglected, and that therefore the observed deviation might be assumed to result only from the temperature, or from the friction of the thermo-electric couple. A course of rather tedious experiments have shown me that this supposition is most erroneous, and utterly deceptive, when applied to refined investigations and highly susceptible instruments. A multitude of contradictory and incoherent facts accumulated themselves like a chaos, before I arrived at this source of error." "A voluminous journal of attempts was multiplied by the unexpected thermo-electric influence of the rheophores destroying its value."

For my own part, I can fully appreciate the difficulties and incoherent results which obstructed Professor ERMAN's progress in this obscure investigation. The same, along with many others, had bewildered me; and to such an extent that I more than once contemplated the abandonment of the subject.

The adoption of new methods and the performance of multiplied experiments have given me some confidence in the statements which here follow, although they by no means correspond with results that have been published by other investigators.

It is convenient, in the first place, to state the conclusions to which my experiments have led me, and which I have called Laws for want of a more appropriate term. But I am aware that they should be the proved expression of a far greater number of accordant facts than I have been able to elicit before they can in strictness be admitted as the general laws which determine the deflections of the magnetic needle when under the influence developed by the attrition or thermo-contact of dissimilar metals.

LAW I. The agent which causes the deflection of the galvanometer needle may be brought into action either by contact with each other at unequal temperatures of certain metals, metallic ores, or some forms of carbon ; or by their attrition against each other, whether at equal or unequal temperatures.

LAW II. When two different metals,* and sometimes two separated masses

* To avoid perplexity I omit ores and carbon, although they are subject to many of the laws.

of the same metal, are rubbed against each other, deflection will result, the degree of which will vary with the metals or metal employed, and to a certain extent with the force and rapidity of attrition. This deflection will take place in air, or under the surface of mercury, or of aqueous, oily, ethereal, or alcoholic liquids.

LAW III. When two different metals, and sometimes two separated masses of the same metal, are brought in contact, at unequal temperatures, deflection will generally take place, the degree being determined by the nature of the metals or metal, and the difference of the temperatures at which the contact is effected.

LAW IV. If two different metals be at the same temperature throughout their mass, whether it be high, low, or mean, contact will not produce deflection.

LAW V. 1. Sometimes the deflective energy developed by attrition, at unequal temperatures, is more effective than that produced by contact, when the temperatures are in a state of inequality to the same amount as that at which attrition took place.

2. And sometimes the deflective energy of two metals in contact, at unequal temperatures, is more effective than that developed by their attrition when their temperatures are in a state of inequality to the same amount. The result 2 is of less frequent occurrence than 1.

LAW VI. When two metals, at unequal temperatures, produce deflection on the same side of the magnetic meridian, both by their attrition and contact; while if their temperatures be equal, their attrition causes deflection on the opposite side of the magnetic meridian ; it is a consequence that the deflection caused by attrition or contact of the metals, while their temperature is adequately unequal, will change to the opposite side of the magnetic meridian if attrition be employed during the period of their near approach to and arrival at equality of temperature.

LAW VII. If the deflections be all on the same side of the magnetic meridian which are produced, first, by the contact or attrition of two metals at unequal temperatures, and, second, by their attrition at equal temperatures; then it is but another mode of expression to say that there can be no such reversal as in Law VI.

Law VIII. Whether these deflections will take place on the eastern or western side of the magnetic meridian will be determined by the *relative* temperatures at which contact or attrition of the metals has been effected; and by the peculiar influence of the metal that is placed in connexion with each extremity of the coil of the galvanometer.

Law IX. The condition necessary to the production of deflection, by contact of two different metals, is that heat shall be at that moment entering or leaving one of them; or that heat shall be unequally entering or unequally leaving both of them; no matter whether the inequality depend on difference of supply, of conduction, or of capacity; or on unequal diffusion of heat arising from difference of mass of the metals; or on more than one, or all of these causes conjointly. The deflection, caused by the unequal entrance of heat into metals in contact, will be on the side of the magnetic meridian opposite to that on which it would be if heat were leaving them unequally.

Law X. The form of the metal influences its effects: rods and rings for the most part act differently from hemispherical masses. If a metal rod be heated at one end, and applied or rubbed to a rod of a different metal at a much lower temperature, the former will most generally be thrown into a state of polarity, each end being capable of producing deflection opposite to that which the other end produces: the latter rod when similarly treated will evince a contrary polarity. Either rod will reverse the deflections mentioned if its other end be the sole heated one. But the application of an equal and adequate heat to the whole extent of a rod will cause it, in the case of some metals, not only to lose its polarity, but even the power of producing deflection, the needle remaining at zero; and in other cases, although the polarity will be destroyed, the rod will act in the same manner and with the same energy, with regard to producing deflection, as a hemispherical mass would have done at the same temperature. In many cases the polarity may be destroyed, and all effect of that metal rendered null, by the nice adjustment of the relative portions of the rod heated and not heated.

Law XI. If two rods of different metals, properly connected with the galvanometer, be placed in contact with each other at one point; and if a corresponding small portion of each be subjected, at the point of contact, to an equal and adequate temperature, above or below that of their respective remainders, they will produce deflection on the side of the magnetic meridian opposite to

that on which the deflection would have *temporarily* taken place, had the metals been, throughout their mass, exposed to that temperature. If the portions of the metals acted on be raised above the temperature of their remainders, the deflection will be on the side of the magnetic meridian opposite to what it would have been had these parts been reduced to a temperature below that of their remainders.

LAW XII. The deflection produced by thermo-contact or attrition will be always reversed when the exciting metals connected with the extremities of the galvanometer coil are transposed.

LAW XIII. When deflection is produced in consequence of the attrition or contact of two metals, one of which is hotter than the other, the deflection will *in many cases* change to the opposite side of the magnetic meridian if the hotter metal be adequately cooled, and the cooler metal be adequately heated, the contact or attrition being renewed. Any two metals which, when associated, comport themselves in this manner may fail to do so when differently associated.

LAW XIV. The deflection produced by the mutual attrition of any particular pair of metals will take place at all temperatures of these metals on the same side of the magnetic meridian, provided that the temperature is equal or nearly equal in both. As this direction of the needle is always the result of the attrition of these particular metals, when they are in their ordinary state of equality of temperature, it may be conveniently called the *natural* deflection of any pair of metals.

LAW XV. The deflection caused by chemical action of a menstruum on two associated metals has no observable dependence on, or connexion with, that produced by thermo-contact or attrition of these metals.

LAW XVI. The agent developed by the attrition of two metals, even when rapid, forcible, and long continued, does not manifest any decomposing influence on chemical compounds. It is not conducted by aqueous liquids, even when containing saline impregnations.

To these sixteen laws, in the expression of which the language of hypothesis has been avoided, I conceive may be referred the whole of the complicated phenomena which thermo-contact and attrition of metals and other substances produce; at least as far as researches have yet disclosed.

In the following statements, when reference is made to the galvanometer,

I use the terms "zinc side" and "silver side." When it is mentioned that any process was effected at the zinc side, it means that the substance concerned was connected with that end of the galvanometer coil, which, if in communication with the zinc element of a voltaic combination of zinc, silver, and dilute sulphuric acid, would cause that end of the upper bar of the compound, or astatic needle, which naturally points to the north, to turn towards the west. The silver side, therefore, means the end of the coil which, with that same deflection, would be in connexion with the silver element of such a combination.

When eastern or western deflection is mentioned, it signifies that the end of the upper bar of the compound needle, which naturally points to the north, has moved in these directions. For many of the experiments described a galvanometer of extreme susceptibility is required, in order that the results may be unequivocal. I have described one in the Transactions of the Royal Irish Academy, Vol. XXII., Part 3, which answers perfectly, and it was used in these experiments.

In most of the following experiments the metals to be tried were formed into hemispheres, the flat faces of which were polished: they were of an inch and quarter diameter across the flat circular face; the round back of each had a neck to which the rheophore wire was firmly fixed; and each hemisphere was attached by its neck to a wooden handle. The rheophore wire was generally of silvered copper nearly as thin as a human hair; for by this contrivance the portion attached to the neck of the hemisphere always maintained the temperature of the neck itself; hence, by Law IV., the contact of the neck and rheophore did not develope any deflecting agency, and there was no interference with the indications of the hemispheres experimented on. These extremely fine rheophore wires are only fitted for metals which act on each other with a certain intensity; when the deflecting power of the metals is weak, the rheophore must consist of a somewhat thicker wire; but even such wire, when connected with the hemispheres, does not interfere with the deflections. In the case of platinum, palladium, and gold, I made use of thin plates of these metals fastened to wooden handles. Such handles are indispensable, because, if the metallic hemispheres, or plates, were held in the hand, their temperature would be interfered with, and erroneous results obtained.

The means made use of for bringing the hemispheres to any required tem-

perature, or to an equality of temperature, were to immerse them in water, whether hot or cold. The necessary cold was sometimes attained by keeping masses of ice in the water. To produce equality of temperature in this manner is not so easy as might be imagined—so small is the difference that will give evidence of its existence. If ice be used, different parts of the water will be at temperatures not exactly the same. Even when the water is hot, the vessel, or the thick parts of it, will vary; and by contact the metallic hemisphere may participate in the difference, or the wooden handles may defend parts of the metal. The best way is to allow the hemispheres and handles to remain an adequate time in the water, using almost constant agitation, until centrally and externally they be of the same temperature as the water.

I have sometimes used the expression "adequately hot," or "adequately cold," to signify that decided effects can only be produced by a considerable difference of temperature. In a few instances I found that the hemispheres acted better when their flat faces were wet; and this does not alter their indications. Instances occur in which the deflective energy of the metals is so feeble that attrition, effected by the hemispheres held in the hands, is inadequate; in such cases I had recourse to a piece of revolving machinery, which will be described hereafter, and thus the metals were made to rub against each other with the greatest rapidity. I now proceed to explain and amplify these different Laws.

LAWS I., II., III. On the first, second and third Laws, there is little to remark. It is not metals alone that exhibit the phenomena; many of their ores exhibit the same powers, but generally with less energy. Newly burnt boxwood charcoal, rubbed against a revolving plate of bismuth, acted on the galvanometer so energetically, that the needle traversed the whole circle with vivacity. That peculiar carbon, also, which is deposited on the interior of iron gas retorts long in use, acts as a metal. Either of these forms of carbon comports itself with bismuth, in all respects, like antimony, with regard to the direction of the needle, when acted upon by thermo-contact, or attrition. Graphite also acts similarly.

In appreciating the effect of temperature on an associated pair of different metals, which produce deflection by contact, it has been supposed by ERMAN that the temperature of the surrounding atmosphere is the standard at which no deflection would be produced by contact, and that by raising or lowering

the temperature equally in both metals above or below that standard, the deflection would take place. There is in this proposition more than those who rely on it are perhaps aware of, as will be shown under the consideration of the fourth Law. For the present it is only necessary to observe, in support of Law III., that the temperature of the surrounding media has no connexion with the subject; that the cause of deflection is *difference** of temperature between the two metals, and not its elevation above, or depression below, that of the air. Thus, when the temperature of the air was 60°, a pair of bismuth and antimony would produce deflections, whether one of the metals was at 30°, 60°, or 100°, the other being 212°. The deflection of greatest amount is produced by the greatest difference of temperature.

LAW IV. I have verified this Law in the case of gold, platinum, palladium, silver, copper, brass, German silver, nickel, zinc, cadmium, tin, lead, antimony, arsenic, iron, bismuth, and mercury. Hemispheres, or plates, of the first sixteen of these metals, mounted with capillary rheophores and wooden handles, in the manner already described, were left in pairs, lying near each other for some hours, so that they all assumed the same temperature. By bringing the metals of each pair into contact, taking care to avoid friction, there was not the slightest deflection of the galvanometer with which they were connected. The trials were made at different temperatures of the air, between 36° and 70°. They were also made at temperatures varying from 70° to 212°, in which case the method adopted was to place the two hemispheres in a vessel of water, of the required heat, at a little distance from each other: the chemical action of the water on the metals caused deflection; when it was judged that both were at the same temperature they were brought into contact; the needle came to zero, all deflection being at an end. In these experiments the rheophore wires must be of the greatest tenuity, for reasons that will hereafter appear under consideration of Law IX.

This statement differs from that of ERMAN, in which he informs us, that having equally heated a bar of bismuth, and another of antimony, to 100° or 111° Fahr., their contact produced 30° of eastern deflection; and also from his experiment, in which, by equal reduction of the temperature of both bars, their

* The term is here used for sake of brevity: under consideration of Law IX. the exact meaning will appear.

contact caused western deflection. I conceive that Professor ERMAN was misled in these two cases by a circumstance which shall be hereafter noticed.

It is obvious that, in my trials, the rheophores could not have caused any interference; for they were maintained at the same temperature as the hemispheres or plates by being exposed to the same atmosphere or the same water, and the incapability of the hemispheres to cause deflection proves equally that of the rheophores when at the same degree of heat.

LAW V. The first part of this Law (marked 1) may be proved by many examples. If a hemisphere of antimony and one of nickel, one cold, the other hot, be brought into contact, the deflection will scarcely exceed 5°, but attrition will send the needle perhaps 60°. The same observation may be made of German silver associated with iron. Many other metals might be instanced. The Law also holds good with regard to that peculiar kind of carbon which is deposited in the interior of old gas retorts: if a large mass of this, which has been long heated in boiling water, be brought in contact with a piece of cold bismuth, a deflection of about 35° will be produced, but attrition will cause the needle to start off 20° or 30° farther.

The second part of the Law (marked 2) is thus exemplified: when adequately hot bismuth (as 200°) is on the zinc side, and antimony (below 50°) on the silver side, if the metals, without being allowed to remain in contact a moment, are at once made to rub against each other at the instant of their first application, there will be a certain amount of eastern deflection; and the needle, having attained its maximum, will remain stationary. But let the attrition be discontinued, and the contact maintained; it will be found that the needle will proceed still more eastward than before, perhaps to the extent of an additional 20° or 30°, proving that, in this case, contact was more powerful than attrition, both being effected at the same temperatures. Renewed attrition will then suddenly reduce the deflection, because the two metals are now somewhat nearer to equality of temperature; contact will again increase it; and this alternation may sometimes be effected several times before the temperatures are equalized. It thus appears that the effect of attrition is not to be viewed as the mere result of simple contact.

LAWS VI., VII., VIII. These Laws include facts which appear to me to have been misunderstood. As an example, let a hemisphere of bismuth, with its

wooden handle, be connected with the zinc side of the galvanometer; and a hemisphere of antimony with the silver side. Both metals being at the temperature of the air, their *natural* deflection when rubbed together would be western. If the bismuth be now thoroughly heated by being plunged in boiling water, on withdrawing it, and bringing it in contact with the cold antimony, the needle will move eastward; and while it is thus moving, if the two metals be rubbed together, the eastward motion, far from being interrupted, will continue until the needle reach perhaps 90°. If the attrition be continued, the needle will very slowly pass to zero; and, having reached it, will move on perhaps to 80° west, not very far from which it will remain while attrition is continued.

LAW VI. The experiment will succeed in a very striking manner with the revolving apparatus hereafter to be described.

The circumstance that during attrition the needle passes from east to west (a change which obtains equally in the case of many other associations of metals) has given origin to the belief that attrition always reverses the deflection produced by thermo-contact, and that such reversal is a counteracting effect of the influence of attrition, as such, on that of contact. It is proper to state, at full length, grounds of dissent from this opinion.

In the instance under consideration, the effect of bringing hot bismuth in contact with cold antimony, as above mentioned, is to produce eastern deflection. If, after the contact has continued a moment or two, the metals be moderately rubbed together, the deflection, instead of being reversed, as a peculiar effect of attrition, is continued in the same direction as at first; at least this is true while there is considerable inequality of temperature between the metals, and more so when cadmium is substituted for antimony. But in the progress of rubbing, the bismuth is reduced in temperature by imparting heat to the antimony: the two metals are brought so near equality, one by parting with heat, and the other by receiving it, that, in conformity with Law XIV., the *natural* deflection begins to take place, which, when the two metals are respectively stationed at the above-mentioned ends of the coil, is western: hence there is a change of direction from east to west. (Law VI.)

In accordance with this view, it will be found that the smaller and fewer are the touching points of the two metals applied to each other, the greater

will be the eastern deflection, and the more slowly will the needle come round to the west; because, in that case, the bismuth points, abundantly supplied from the mass, do not lose, and the antimony does not gain heat rapidly.

When the rubbing surface of the antimony is very small, as a fine point, there may be no eastern deflection, because the point immediately assumes nearly the same temperature as the hot mass of bismuth, before the inertia of the needle can be overcome by the tendency to eastern deflection. If the surface of the antimony be relatively very large, and the mass considerable, the east deflection is trifling, and the inversion rapid; for the small surface of bismuth is almost immediately cooled nearly to the temperature of the antimony. If the bismuth, at a low heat, be rubbed against the cold antimony, there will be no eastern deflection; and therefore there can be no reversal: the deflection natural to the metals prevails, because the difference of temperature is not adequate to overcome that tendency: and hence the needle at once moves to the west.

Thus in such cases, and there are many, attrition, instead of reversing the deflection caused by thermo-contact, induces and continues a deflection in the same direction, provided the temperature of the heated metal be adequate, and maintained. Attrition has nothing to do with the reversal, until, by gradually equalizing the temperature of the metals, it permits another Law (XIV.) to come into operation, which, it so *happens*, has a contrary effect to that of unequal temperature. In fact, attrition, in this case, instead of *causing* a reversal of deflection, induced by thermo-contact, merely *permits* by its continuance a restoration of a deflective tendency natural to these metals when rubbed against each other, their temperatures being at the time equal, or not very different. Even when the temperatures are very different, they may not be adequately so: there are instances wherein the natural deflective tendency is so strong that it will prevail. Thus when bismuth and arsenic suffer attrition against each other, unless the former be 212°, and the latter below 50°, the eastern deflection will not be produced.

Generally, the deflective energy developed by attrition of two metals, at very unequal temperatures, transcends and therefore overpowers the opposite deflecting energy which is produced by attrition of the metals when there is very little or no difference between their temperatures. But in proportion as

the inequality of temperature diminishes, the effect of attrition becomes more effectual in producing the *natural* deflection on the opposite side of the magnetic meridian, which in some instances is very powerful.

Numerous cases range themselves under this class of phenomena, in which the direction of the needle is thus *suffered* to reverse itself by attrition. Instead of being examples of an active reversal, they are in fact so many instances opposing the alleged universality of this effect of attrition.

In the foregoing experiments I used the hemispheres already described. In order to obviate any doubt concerning the interference of the rheophores, or the shape of the metals employed, the experiments were varied by laying aside the hemispheres, and substituting rods of the two metals, connected with the binding screws by means of capillary copper wire. The bismuth rod, connected with the zinc side of the galvanometer, was totally immersed in hot water, along with that part of the copper wire which was attached to one of its extremities: the antimony rod, on the silver side, lay on the table at the temperature of the air. The end of the bismuth rod, namely, that end which was not connected with the copper wire, was raised about an eighth of an inch out of the water, by its wooden handle, and the antimony rod, held also by its wooden handle, was instantly rubbed against the extremity of the bismuth; there was immediate eastern deflection. From the nature of the experiment, the only way in which both metals could now be brought to the same temperature, and the direction of the deflection changed to the natural state (Law XIV.), was to plunge both into the water, the attrition being still continued. This done, the needle speedily went round many degrees to the west permanently.

In this trial, the point of junction of the rheophore wire with the bismuth rod was submerged in hot water; and the other rheophore required no artificial means to maintain it at the same temperature as the antimony rod, because both were exposed in the open air. Thus the temperature of each rheophore and its rod being equal in the respective cases (Law IV.), there could be no interference of the rheophores in the deflections produced by the attrition of the metals.

As the Law (VII.) which these trials were intended to illustrate is important to the explanation of several phenomena, I varied the experiment in the following manner, in order to discover whether mass, or mode of attrition, has

any influence in the result. A wooden wheel four inches diameter, shod with a ring of bismuth weighing twelve ounces, was fixed on the axle of the revolving machine hereafter to be described.

In revolving, the bismuth rubbed against the end of a cylinder of antimony, and both the metals were connected with the galvanometer by capillary copper wires, one of which was so contrived that it did not suffer by twisting as the wheel revolved. The ring of bismuth, connected by its rheophore with the zinc side of the galvanometer, was equally heated by a spirit lamp, while in motion, its flat periphery being made to rub against the antimony. The needle instantly moved to the east; but as the motion of the wheel was continued, the needle came round slowly to the west, and stood permanently at 65°, when the antimony became heated nearly to the same degree as the bismuth. One of the rheophores, being bedded in the substance of the bismuth ring, must have been at the same temperature as the bismuth: the other rheophore and the antimony were similarly circumstanced. Here everything coincided with former trials.

The next step in the inquiry was to make corresponding experiments with various other associations of metals and alloys, in order to discover whether their habitudes resemble those of bismuth and antimony.

The following is a list of some metals which agree. Sometimes the revolving wheel was used, sometimes hemispheres, and sometimes plates:—

Bismuth with antimony.
Bismuth with lead.
Bismuth with tin.
Bismuth with iron.
Bismuth with copper.
Bismuth with German silver.
Bismuth with nickel.
Bismuth with silver.
Bismuth with gold.
Bismuth with platinum.
Bismuth with palladium.
Bismuth with hard amalgam of zinc and mercury.
Bismuth with cadmium.
Bismuth with arsenic.
Nickel with brass.
Nickel with lead.
Nickel with iron,
German silver with tin.

On the collocation of the metals in the foregoing Table many particulars depend, which may be thus classified:—

1. If the first-named metal of each pair be connected with the zinc side of

the galvanometer; and the second with the silver side; and if the two metals, at the same temperature, be rubbed against each other, the deflection will in all cases be west of the magnetic meridian.

2. If the first-named metal, being on the zinc side, be adequately and equally heated throughout its mass, while the second, on the silver side, is adequately cooled, either contact or attrition will cause eastern deflection.

3. If the first-named metal on the zinc side be adequately cooled, and the second on the silver side be adequately heated, either contact or attrition will cause western deflection.

4. The converse of the foregoing propositions is, that if the second-named metal be connected with the zinc side of the galvanometer, and the first with the silver side, attrition against each other, provided they are at the same temperature, will cause eastern deflection.

5. If the second-named metal on the zinc side be heated, and the first on the silver side be cold, either contact or attrition will cause eastern deflection.

6. And if the second-named metal on the zinc side be cold, and the first on the silver side be heated, contact or attrition will cause western deflection.

From this arrangement of metals and effects, we can deduce the results of attrition and thermo-contact of any particular pair, mentioned in the foregoing list, by the aid of the following paradigm. Let bismuth and antimony be taken as the representatives of any other pair placed in the same order in relation to each other as in the foregoing list.

A. Bismuth on the zinc side, antimony on the silver side.

1. The attrition of the two metals when at the same temperature will give western deflection.

2. When the bismuth is hot and the antimony cold, either contact or attrition will give eastern deflection.

3. When the bismuth is cold and the antimony hot, either contact or attrition will give western deflection.

B. Antimony on the zinc side, bismuth on the silver side.

4. Attrition of the metals when at the same temperature, will give eastern deflection.

5. When the antimony is hot and the bismuth cold, contact or attrition will cause eastern deflection.

6. When the antimony is cold and the bismuth hot, contact or attrition will cause western deflection.

From this statement it is plain that if the foregoing six conditions were laid down for all the associated pairs, that one marked 2 would in each case *permit* the needle to pass from east to west by continued attrition; and that one marked 6 would allow it to change from west to east by the same treatment. In all these instances the reversal would, as already explained, be *simulated;* that is, it would happen merely in consequence of the cooling of the metal to so low a degree as to remove it from the operation of the law under which that deflection had been produced: it would be a passive not an active reversal (Law VI.); and would not arise from any direct opposition of properties between contact and attrition.

It is obvious that the foregoing paradigm can only apply to the associated pairs of metals when in each case they are placed relatively to each other as in the list. The six conditions apply, for instance, to bismuth and antimony, but not to antimony and bismuth: were the order antimony and bismuth, and so in the rest, the conditions of simulated reversal would be those marked 3 and 5, instead of 2 and 6. But other associations may be formed which comport themselves differently from those in the preceding list: in order to make them agree with conditions 2 and 6, they must be arranged at the ends of the coil in the order given in the following examples, and the temperatures must be reversed.

Lead with antimony.	Copper with antimony.
Tin with antimony.	Copper with iron.
Tin with iron.	Brass with antimony.
Silver with antimony.	Arsenic with antimony.
German silver with antimony.	German silver with arsenic,
Platinum with antimony.	Copper with cadmium.

1. When the first-named metal of each associated pair is on the zinc side, and both are at the same temperature, attrition gives western deflection.

2. If the first-named metal, being on the zinc side, be cold, the other hot, the deflection by contact or attrition is east.

3. If the first-named metal on the zinc side be hot, the other cold, contact or attrition gives west deflection.

4. When the rheophores and metals are transposed in the binding screws, attrition at equal temperatures will cause east deflection.

5. If the second-named metal, now on the zinc side, be cold, and the first named hot, the deflection will be east.

6. If the second-named metal, now on the zinc side, be hot, and the first cold, the deflection will be west.

It thus appears that, in conformity with the paradigm, the conditions 2 and 6 are those under which the simulated reversals would take place; but in 2, the first-named metal, being on the zinc side, must be the cold one; and in 6, the second-named metal, being on the zinc side, must be hot, and its associate cold: hence the conditions 2 and 6 are reversed with regard to temperature.

In short, a true reversal could not take place unless attrition and thermo-contact were capable of producing opposite effects under the same circumstances of temperature and arrangement of the metals. No instance of this kind occurred during numerous experiments. Indeed, it would be surprising if opposite effects could result from processes so similar in their nature as contact and attrition, under circumstances exactly the same.

There are many associations in which it would be impossible that attrition should even simulate a reversal of the effects of contact, no matter in what relation the metals are placed with regard to each other, or their temperature. Thus a third class of metallic associations exists which differs entirely from the former two. A number of these shall be adduced, not only as examples, but with an ulterior view which will appear hereafter.

Lead with iron.
Zinc with iron.
Silver with iron.
Platinum with iron.
Palladium with iron.
German silver with iron.
German silver with nickel.
German silver with silver.
German silver with zinc.
German silver with brass.
German silver with copper.
German silver with lead.
German silver with cadmium.
Antimony and iron.
Nickel with arsenic.
Nickel with antimony.

The last-mentioned pair of metals is an excellent example of this class, its deflections, whether at equal or unequal temperatures, being well marked.

The first-named metal of each pair being on the zinc side, and the second on the silver side, attrition at equal temperatures will cause western deflection; it will also be western whether the first or second named metal be hot, its associate being cold. And when the rheophores are transposed at the binding screws, the deflections will all be eastward, whether the associated metals are at the same temperature, or one at a higher temperature than the other, no matter which is hot or which is cold. It is therefore obvious that under no circumstances of these metals could attrition even simulate a reversal of the deflection caused by contact.

It is on account of this class of metallic associations that Law XIII. is not expressed as universal in its application. In the annunciation of that law it is said, that " the deflection will in *many* cases change to the opposite side," &c., because the associations above described do not so change. Notwithstanding this the law *may* be universal; for it is easy to understand that whatever influence the hot metal exerts on the cold one in order to produce a certain deflection, the latter when hot may happen to produce the same effect with the former metal when cold.

From all that has been said, it is obvious that if the contact of two metals, at unequal temperatures produce deflection in the same direction as that caused by their attrition under the same circumstances, and the deflection is on the side of the magnetic meridian, opposite to that which the attrition of the metals would have occasioned if their temperatures had been equal, then a reversal takes place which I have called *simulated*, because it does not arise from any opposition between the effects of contact and attrition, but from one effect supervening on the cessation or diminution of another. Thus, the reversal is passive, not active; and no such phenomenon occurs as an active reversal.

But when the deflections, produced by attrition and contact of the associated metals at different temperatures, are all the same for the three conditions which may take place at each extremity of the galvanometer coil, then even simulated reversal is impossible. All this is very plain.

LAW IX. This law is founded on probability and experience, as well as on the difficulty of admitting the truth of the common opinion. It is generally believed that the mere condition of difference of temperature in the associated metals is the cause of the deflections which their contact produces. It appears

to me that this opinion has never been established. A persistent temperature above or below that of the surrounding media, is never the condition of metals brought into contact at unequal temperatures, for the purpose of producing deflections; hence we know absolutely nothing of what the result would be if they could be presented to each other in such a condition. What we do know is, that when deflections are produced by metals at unequal temperatures, the colder metal is receiving, and the warmer is parting with heat at that moment; that is, the mediate agent in causing deflection is the *motion* of heat, provided the language be permitted of those who consider heat to be imponderable elementary matter which enters into, and passes out of, other kinds of matter. The quantity of heat, even although different in the metals, would not be a sufficient cause of deflection; for the quantity of heat may be different, yet the thermometric indication may be the same: and under such circumstances no deflection would result.

Thus quiescent heat, no matter what its amount or difference of quantity, is not known to affect metals in such a manner as to produce deflection; and it is the entrance or departure of heat, in other words, its motion, that seems to be effective. It is not probable that a body, during the process of heating or cooling, ever remains of the same temperature for one moment of time. Heat, if ever stationary in a body, can only be so when that body and all the surrounding media are at the same temperature; but metals, when in this state of equilibrium of heat, do not by contact produce deflection. As soon as heat begins to enter or leave either or both unequally, then they are capable of affecting the needle; and although in the foregoing pages I have frequently mentioned the efficiency of unequal temperatures, it was for the sake of brevity, and not with a view of conveying any opinion different from what has now been explained. It will presently appear that the distinction here made is important.

The following experiments coincide with the preceding views. Take two rods of different metals, each about twelve inches long, and a quarter of an inch in diameter; antimony with bismuth, or German silver with brass, and many other combinations will answer. Tie the rods together at one end with thread, so that they shall form the letter V; immerse the tied ends in boiling water to the depth of about one-third of the length of the rods, and continue the boiling. It is to be presumed that the immersed portions have at length assumed the

temperature of the water; yet if the rods be now connected with the galvanometer, there will be immediate deflection, although, by the conditions of Law IV., it might be expected that none would follow. This deflection will continue until the water has cooled to the temperature of the atmosphere, and then the needle will have arrived at zero. During the continuance of the deflection, heat was entering both rods of metal, but with different degrees of rapidity, because of difference of conducting power, or of the quantity of heat necessary to produce the same temperature in both rods, and other causes. As fast as heat entered, it passed out through the portions of the rods which were not immersed, and was continually dissipated in the air, while new portions entered from the water. Hence there was a constant current of heat passing through the metals, and hence they were continually in that condition, whatever it may be, which produces deflection, until no more heat could be supplied or put in motion.

It might appear that, although this experiment supports the law under consideration, it militates with Law IV. In fact it might be conceived to prove that metals, by being equally heated above the temperature of the surrounding media, are capable of causing deflections, as Mr. Erman and others supposed. By a little variation of the experiment it will be shown that no such inference ought to be drawn. If the two rods, tied as before, be connected with the galvanometer by capillary copper wire, and one-third plunged in boiling water, it will be found, in conformity with what has been just explained, that the deflection will continue so long as the temperature is maintained above that of the surrounding media. But if the rods, still tied, be entirely submerged in boiling water, so that all parts be brought to the same temperature, and no current of heat, as it may be expressed, is passing through them, the deflection will in a minute or two cease. The needle having arrived at zero will there remain, and there will not be the least variation unless circumstances should cause one of the rods to change its temperature, such as unequal cooling of the water or containing vessel; the most trifling inequality will produce a deflection.

In these experiments, if, instead of hot water, we use water cooled with ice, the converse process will take place, provided the atmosphere at the time is at a higher temperature than the cooled water. A deflection will result, but it will be on the opposite side of the magnetic meridian; this will continue until the temperature of the metals and water rise to that of the surrounding media,

and then the needle will stand at zero. In this case heat from the atmosphere enters the portions of metal not covered by water; it is then communicated to, and absorbed by the water; thus, a retrograde current of heat is created, and hence the opposite deflection. The transmission of heat by the metals is unequal on account of their unequal conducting powers and capacities.

It is a consequence of this law that, in general, if two metals in contact, connected with the galvanometer by capillary rheophores, be equally subjected to the action of the same degree of heat or cold throughout their whole mass, as by being immersed in hot or cold water, there will be, at first, a deflection, which, however, will speedily cease, and the needle will settle at zero; heat was either entering or leaving the metals unequally, hence the opposite deflections according to the current of the heat; but all deflection will cease when the capacities for heat are satisfied.

These transitory deflections have misled some philosophers into the belief that they are produced by an equal elevation or depression of the temperature of both metals above or below that of the surrounding media. If I am correct in the laws laid down, and I know of no reason to doubt it, a change of temperature, *equal in both metals*, does not impart to them the power of producing deflections; although deflections will occur when the metals are *in progress of arriving* at equality of temperature, but, that point once attained, all deflection ceases.

Law X. The facts on which this law is founded are very perplexing, so difficult is it to disentangle the complications which take place. A few of the leading ones only shall be noticed.

Rods of metals, under certain circumstances, act differently from hemispheres: the latter produce but one kind of deflection for each mass, at a given temperature and at the same end of the coil; the former give an opposite deflection for each end of the rod dependent on its temperature. Let a rod of German silver, eight inches long, and a quarter of an inch in diameter, be connected by a capillary copper wire to the zinc side of the galvanometer, and a similar rod of bright iron to the silver side. If one end of the German silver rod, adequately heated by a spirit lamp, be applied or rubbed to the cold iron rod, a strong western deflection will result; its cold end would give eastern deflection. The contact being continued, let the cold end of the German silver rod be slowly heated, the deflection will gradually lessen, and at length

become null; the needle will stand at zero, for the polarity has been destroyed. Or if the German silver rod had been originally heated throughout equally, as in boiling water, there will be no deflection when it is brought in contact with the cold iron rod.* If the iron rod on the silver side be heated at one end, its contact with the cold German silver rod will cause western deflection, and will manifest polarity; but, when it is heated equally throughout, it will be incapable of producing deflection. Thus these two metals agree in their incapability under the circumstances stated. But if one end of either be hotter than its other end, although both be hot, there will be corresponding deflection.

But this incapability of producing deflection, which arises from equal diffusion of high temperature throughout the whole rod, is not common to all metals. With a bismuth rod on the zinc side, and an antimony rod on the silver side, if one end of the bismuth be heated, it will, by contact or attrition with the cold antimony rod, give western deflection for the hot end, and eastern for the cold end. If the whole of the bismuth rod be heated equally throughout, its polarity will be destroyed; but the needle, instead of standing still at zero, will pass to the east, because the rod no longer acts as such, but as a hemisphere, on account of the great natural energy of these metals in thermotribo-electricity. The case will not correspond when the rod of antimony is the heated one; for whether it be heated at one end only, or throughout its whole extent, its contact with the cold bismuth will be the same, viz.—eastern deflection on the zinc side, and western on the silver side.

If a bismuth rod, on the zinc side, be heated at one end, and made to act on a cold iron rod on the silver side, there will be western deflection; or eastern if the heat be equal throughout. But if the iron rod on the silver side, be heated at one end only, or equally throughout its whole extent, it will, in either case, give western deflection by attrition or contact with the cold bismuth.

If German silver be substituted for bismuth in the foregoing experiment, and a tin rod for the iron, the same application of heat, as before, will produce the same deflections; the tin whether hot at one end only, or throughout, will impel the needle in the same direction. Corresponding results will be obtained with rods of tin and bismuth, or tin and antimony.

* Attrition will sometimes give 2° or 3° west.

When the rods employed are antimony and German silver the case is different: either rod heated at one end only, and applied to the other cold, will cause western deflection. But when the antimony is heated throughout, it gives with cold German silver a feeble eastern deflection.

It is a singular circumstance that if two rods of bismuth be used, one on each side of the galvanometer, either rod heated throughout and rubbed to the other, will cause an extensive swing of the needle, but if the same rod be heated at one end only, it will send the needle in the opposite direction. If two rods of antimony be similarly treated, the heated rod, whether it is so partially or entirely, will cause eastern deflection by attrition to the other.

In order to try the effect of bending a rod into a circular form and uniting its ends, I caused a thick ring of bismuth to be cast: it weighed twelve ounces; its diameter was nearly five inches. This being connected with the zinc side, and a mass of antimony with the silver side, it was found that by heating about an inch of the bismuth, and rubbing it against the cold antimony, western deflection resulted; but when the whole ring was equally heated, the same contact caused the needle to pass to the east. Thus the ring acted in the same manner as a rod.

By comparison of the foregoing experiments it will appear that the deflections produced by rods are frequently different from those caused by hemispherical masses. The experiments require much circumspection; many attempts may be necessary to obtain true results. The least difference in the heat of the two ends of a rod, when they are intended to be equal, will sometimes give a false deflection.

It thus appears to be true, with regard to this law, that metals divide themselves into two classes:—1st. Those which, when associated with certain other metals, give deflections on opposite sides of the magnetic meridian, according as they are heated partially or totally. 2nd. Those which do not so comport themselves when associated with the former class, but give a deflection on the same side of the magnetic meridian, whether they be heated partially or totally. The second class of metals only exist as such, so long as they are associated with the first: for when associated with each other, they change their character and act similarly to the first class. The existence of the two classes is, therefore, not absolute: it is a relative condition subject to the contingent asso-

ciation of certain metals. This iron, when associated with bismuth, gives deflection on the same side of the magnetic meridian, whether it be heated totally or partially; yet iron becomes amenable to tin; for heated partially, it gives a deflection in the opposite direction to that which it causes when it is heated throughout its mass. Other instances might be adduced.

LAW XI. Under the consideration of the preceding Law it was shown that many metals, when in the form of rods, produce opposite deflections according as a part or the whole of the rod has been heated. It is now intended to be shown that these deflections may be exhibited under circumstances apparently amounting to a contravention of Law IV. These circumstances have been much misunderstood; it has been supposed that by merely elevating the temperature of two active metals equally, they would produce deflection by contact; and the following facts apparently support that opinion.

A wire of German silver one-eighth of an inch in diameter, and four feet in length, was connected with one of the binding screws of the galvanometer, without any interposed capillary rheophore; a brass wire of the same thickness and length was similarly connected with the other binding screw; the farther ends of the two wires were tied together with thread. The tied ends were then plunged in boiling water, which immediately produced a deflection of 50° west.

The same experiment was made with much thinner wires of these metals, with exactly the same results.

From each of the first-mentioned pair of wires twelve inches were cut off, and their ends were connected with the binding screws, in the same order as before, by means of capillary copper wires. The two farther ends bent to each other were tied together with thread, and about an inch of the ends so tied was immersed in boiling water. The deflection was west as before.

In this state of things the pair of connected wires was suddenly and totally immersed in boiling water. The needle passed eastward, thus showing, in conformity with what has been explained, Law X., the difference of deflection produced by partial and total heating of the metals. Other associations of metals were also tried; bismuth and antimony succeeded best. A rod of each, twelve inches long, and a quarter of an inch in diameter, was prepared; they were tied together at one end with thread in the form of the letter V; the free

ends of the compound piece were connected with the galvanometer by means of capillary copper wire. The point of junction of the V was then immersed in boiling water to the depth of an inch; there was an immediate deflection to the amount of 90° west. The compound piece was then totally immersed in the water; the needle came round to 15° east.* In these cases the rheophores were proved not to have had any influence; and chemical action of the water was out of the question, as the metals were in strict contact.

In the enunciation of the Law, it is stated that this deflection, produced by total immersion of the associated metals, will be of *temporary* duration. It might appear that the occurrence of *any* deflection, whether the rods were partially or totally heated, would be a contradiction of Law IV., for it might be supposed that as the two metals were exposed to the same temperature, their contact should not cause deflection. But although both metals were exposed to the same source of heat, it is a well-known fact that they do not each absorb heat in such a manner as to produce equal temperatures in equal times; the actual temperature of each metal, owing to this different influx of heat, is therefore unequal; more or less deflection must consequently ensue; and will continue up to the moment when the capacities for heat of the two metals are satisfied, which will be in a longer or shorter time, according to circumstances. The metals having then arrived at equality of temperature, the needle will stand at zero. Thus, it is plain that between the present Law and the fourth Law there is no discordance; all the remaining parts of the former are intelligible without further explanation.

Laws XII., XIII., XIV. need no comment.

Laws XV. and XVI. The consideration of these Laws involves the great question of all,—Are the deflections produced by thermo-contact and attrition

* With some associations of metals it is exceedingly difficult to obtain these results. A rod of tin and one of lead require a galvanometer of exquisite susceptibility. Rods of German silver and iron are apt to deceive; but by dipping the tied ends into boiling water, taking care to keep the remainders cold, and after marking the deflection, removing the tied rods, and leaving them to cool perfectly for some hours, and then plunging them, along with the rheophores, suddenly and totally into boiling water, the opposite deflection will be obtained. This indeed is the best method for all metals.

of the same class as those called voltaic? or, in other words, is electricity the agent in all these phenomena?

In the "Philosophical Magazine" for 1852 I published an essay, in which were adduced reasons for believing that electricity is not a simple elementary fluid, but a compound of several elementary constituents, one of which is the deflecting agent. As soon as I became acquainted with the fact that brisk deflections are producible by attrition of heterogeneous metals, it struck me that, perhaps, the power thus developed might be the deflecting agent, either in a separate form, or at least in a less complicated state than it usually occurs. In order to study this question it was necessary to construct an instrument by which the attrition of metals could be carried on energetically, and for a great length of time, without much labour. I therefore caused the following apparatus to be made; it answered also for some of the experiments already described.

A wooden wheel, four feet in diameter, with a winch for turning it, was adjusted in a heavy, solid frame. The wheel carried a band which passed round a pulley 2·33 inches in diameter, and so mounted in an iron frame that by one revolution of the wheel the pulley revolved twenty times. As the wheel could be made to revolve once in a second, the pulley would revolve twenty times in that period. The axle of the pulley was adjustable to various thick, circular plates of wood, the peripheries of which were each shod with a large, heavy ring of a different metal, which had been turned in a lathe. A socket was placed in such a situation relatively to these rings, that a cylinder of a metal, always of a different kind from that on the circular plate of wood, could by the pressure of a spring be made to rub against the metallic ring as it revolved. Thus, attrition between any two metals could be effected with the greatest rapidity for any required period of time. The socket was lined with ivory. On the frame of the machine were affixed two binding screws, one of which communicated with the revolving ring of metal, the other with the rubbing metal fixed in its socket.

My first trial was made on iodide of potassium dissolved in water, with a little starch also in the solution. The attrition was between bismuth and antimony. With this liquid a small tube was filled, into each end of which

was inserted a platinum wire, one sealed in the glass, the other confined by means of a cork. The platinum wires being connected with the binding screws, the wheel was made to revolve, with great rapidity, during an hour. At the end of this time there was not the slightest symptom of decomposition of the iodide. I also tried the experiment with turmeric paper moistened with solution of iodide of potassium, with no greater effect; although a current of common electricity, which would not have affected the galvanometer, produced a brown spot when passed through the wires for a few moments. Other associations of metals had no better success.

I then made an experiment which, if previously tried, would have shown me the impracticability of producing any decomposition by these means; it was as follows:—The tube with platinum wires, being cleaned out, was filled with salt water, and made a part of the circuit between the bismuth ring and antimony rubber. The galvanometer was also introduced into the circuit. The bismuth ring was now thrown into rapid revolution; but there was not the slightest deflection of the needle, although the platinum wires were separated from each other only one-fortieth of an inch: even this small extent of salt water could not be traversed by the deflecting agent.

To contrast the easy passage of the ordinary voltaic agent through salt water with the impenetrability of this liquid to the deflecting influence generated by attrition of metals, I removed the tube containing platinum wires, and substituted for it a glass tube forty inches long, filled with salt water, and stopped at both ends with corks, through which passed a platinum wire long enough to touch the water within. A zinc and a copper plate, each half an inch square, acted on by water containing as much sulphuric acid as imparted to it a scarcely discoverable taste, were brought into connexion with the copper wires of the long glass tube, in the usual manner; the galvanometer being included in the circuit. The moment the connexions were established, the needle moved slowly, and settled at 60°, proving that this deflecting agent traversed 1600 times the length of liquid, which the other deflecting agent refused to enter at all, and perhaps it would have passed through a hundred times even that extent.

To render this result more striking, the last experiment was repeated, with the single difference of substituting spring water for water acidulated with sulphuric acid. On establishing the connexions, the needle moved 30°:

and when distilled water was substituted for spring water, the needle moved 20°, and stood permanently at 10°.

Here then is an important difference established between these two agents: that one developed by the attrition of metals, far from decomposing chemical compounds, is not even conducted by salino-aqueous liquids. It may be said, in defence of the hypothesis of identity, that the cause is a difference in quantity or intensity of the agent concerned in both. But what appears to oppose this explanation is, that whatever may be the condition with regard to quantity or intensity of this agent which refuses to be conducted by salt water, it is not practicable to reduce the voltaic agent to the same condition. I repeated my experiment, using a thin wire of zinc and an equal one of copper, in place of plates previously employed, the exciting liquid being distilled water. Thus the intensity and quantity were reduced to the lowest degree of both that we are acquainted with, yet the agent thus brought into operation traversed the forty inches of water with ease.

Although the ring of bismuth rubbing against antimony gave a permanent deflection of 75°, which ceased when one-fortieth of an inch of water was interposed in the circuit, I found that when these two metals were immersed in spring water, at the distance of eight inches from each other, a deflection of 4° was produced. Here, then, were the same metals, and the same liquid: the only difference was that in one case a feeble chemical action was in operation, and an agent was in consequence generated which had the faculty of being conducted by water several inches in extent; while, in the other case, an agent was produced which was altogether stopped by a drop.

To ascertain whether the interposition of so small an interval as one-fortieth of an inch of water, in the circuit of what is called a thermo-electric couple, would intercept the deflecting agent, I made the experiment with hot bismuth in contact with cold antimony, and found that the galvanometer was not in the least degree affected. This result, instead of supporting the inference which I have drawn, might perhaps be used as an argument against it; for it is known that a thermo-electric battery will cause chemical decompositions. It may be said that it does so because the power is accumulated; and that if we were acquainted with means of accumulating the power of the bismuth ring revolving against an antimony rubber, decompositions might be equally effected in that manner. This, however, is but the semblance of an opposing argument:

if experiment should hereafter prove the possibility of such decompositions, it would prove nothing in favour of the identity here disputed; it is indeed only what should follow from the constitution which, in my former essay, I have attributed to the electric fluid.*

There is no observable connexion between the deflection produced by chemical action on the two metals, and those caused by their thermo-contact or attrition: they are frequently in opposite directions with the same metals, and the degrees of deflection effected by these several methods on the same metals are very different. Thus the chemical action of spring water on bismuth and antimony is so feeble that the deflection may amount to but 4°, when with the same galvanometer thermo-contact or attrition of these metals will cause the needle to traverse the whole quadrant, or even the whole circle, by a sudden impulse.

Conclusion.

Having now made such observations as seemed necessary on the Laws which I conceive to regulate the motions of the magnetic needle, when under the influence of the agent developed by thermo-contact and attrition of metals, I proceed to consider the question whether these deflections are produced by friction as a primary cause, or by the heat which friction generates. On this subject a difference of opinion prevails amongst philosophers. Professor Erman, the latest authority, conceived that the deflection "is a mere consequence of the heat produced by the action of rubbing."

The fact has, I trust, been sufficiently established, in the foregoing pages, that there are certain metals which, when rubbed together at equal temperatures, give a deflection of an opposite kind to that which results from contact of the same metals at unequal temperatures. Now if the deflection caused by rubbing the metals together at equal temperatures were not produced by friction as a primary cause, but secondarily by the heat consequent on that friction, why should it take place on the side of the magnetic meridian opposite to that on which it would have been had any artificial source of heat been supplied. It may no doubt be argued, that as friction develops heat, this heat might be unequally divided between the two metals, being absorbed more rapidly by

* Philosophical Magazine, 1852.

one of them in consequence of more ready conduction, or greater capacity, or both. But if this were true, it should happen that when these two metals in contact are immersed in hot water, the resulting temporary deflection (Law XI.) should be on the same side of the magnetic meridian as it would have been had the deflection been caused by friction without artificial heat. But on making the experiment, it will be found that when bismuth is on the zinc side of the galvanometer, and antimony on the silver side, attrition of these metals, when at the temperature of the atmosphere, will cause western deflection; but let both in contact be suddenly immersed and rubbed in hot water, and a brisk eastern deflection will result, which will continue until both assume the same temperature.

For my own part I think this fact is sufficient to prove that the deflections produced by attrition are independent of the heat which attrition is capable of developing. There are other considerations tending to the same conclusion. Professor ERMAN observes, that "the point of a needle rubbed against a considerable heterogeneous mass gives immediately the deviation; and an increase of the extent of the surfaces in friction does not appear even to add materially to the intensity of electrization." Are these facts compatible with the belief that heat is generated by a scratch of the point of a needle against a large mass of another metal in such degree as to excite an instantaneous deflection. The friction may be effected under the surface of ice-water, or of boiling water, yet the deflection ensues, it being in both cases western, provided the bismuth is on the zinc side. If friction of two metals in ice-water, or boiling water (the temperature of the metals and water being the same), produce deflection on the same side of the magnetic meridian, how is it possible that the heat generated by a single rub of these metals against each other in ice-water, or boiling water, could excite them by the heat of friction sufficiently to cause a deflection; for there was more than sufficient cold or heat present to neutralize, or overpower, any momentary inequality of temperature which friction, perhaps, of the point of the needle, could occasion.

That it is friction, and not the heat resulting from friction, which causes deflections, is still further countenanced by the fact, that when the attrition of a hemisphere of bismuth against one of antimony is conducted under the surface of hot water, the deflection frequently takes place rather more slowly, and to a less amount, than when it is conducted under the surface of cold water.

Were the heat produced by attrition, the cause of the resulting deflections, we should expect that when deflection had taken place in consequence of the contact of two metals at unequal temperatures, friction, by affording a new source of heat, should increase the deflection in the same direction. But the contrary result is obtained in a number of instances, for the needle passes off in an opposite direction.

If any additional proof were required on this subject, it may be found in the list of metallic associations, constituting the third Table above mentioned. These associations seem to prove that the deflections are not produced by the heat of attrition determined to or from any particular metal of the pair ; for no matter which metal is heated by external means, the needle will be deflected in the same direction when attrition or contact is brought into operation.

In fine, without some violent and gratuitous assumption, it does not seem practicable to sustain the opinion that heat is the agent of attrition in producing these deflections. The foregoing considerations appear to me to render it more probable that they are the result of a peculiar attribute of metals which acts independently of heat, although it is occasionally much modified by that agent.

What the ultimate effect of tribothermo-electric phenomena may be on the present theory of voltaic electricity is not easy to foresee ; ingenious arguments will, perhaps, be contrived to show their compatibility. Hitherto the prevailing opinion, at least in the British Isles, has been that voltaic electricity can only be evolved by chemical agency ; but in tribothermo-electric phenomena the agent, whatever it may be, is developed without any chemical action ; can it then be the same as that which is efficient in voltaic phenomena ?

In the foregoing essay it would have been my wish to have reduced the number of the Laws by expressing them more generally, or to have comprised them, if possible, under one comprehensive Law ; but as they are inductions from facts more or less numerous, and sufficiently distinct, I soon discovered my inability to express them in a more abstract form without omitting important distinguishing particulars, or rendering their enunciation inconveniently complex and intricate.

The laws of thermo-electricity have been unavoidably mixed up with those of tribo-electricity, a consequence of the inseparable nature of the phenomena.

ADDENDUM.

IT is proper to mention that the metals employed in the foregoing experiments were all in their commercial state, it appearing probable that the small quantity of foreign matter present in any one of them must be exceedingly small. In one case, however, I find that I was mistaken: the purity of the metal, which I designated "nickel," was rendered doubtful by some observations which I subsequently made. At my request it was examined by Professor APJOHN, who found that it consisted of nickel, much arsenic, some cobalt, and a little sulphur. The compound nature of this substance does not, however, invalidate the evidence of the experiments in which it was used.